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THE EFFECT OF VARYING FIELD CURING CONDITIONS ON THE 28 DAY STRENGTH OF CONCRETE

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CONTENTS

	Page
Contents	I
Summary	II
Acknowledgements	III
Introduction	1
Objectives	1
Field Tests	1
Laboratory Tests	2
Discussion of Test Results	4
Conclusions	5
Recommendations	6
References	7
Tables	8
Figures	17
Appendix A	21

SUMMARY

Present specifications regarding the initial curing of concrete cylinders in the field within the first 24 hours have been criticized as being too strict. A project was initiated to study the effect on 28 day compressive strength of increasing the initial curing and demoulding period from 24 hours to 48 hours and 72 hours as well as varying the initial curing temperature outside the specified 15°C - 25°C range. Tests were carried out in both the field and laboratory.

Concrete mixes containing 100% type 10 cement and concrete mixes containing 75% Type 10/25% Ground Granulated Blast Furnace Slag Cement were evaluated. In the laboratory, concretes at different initial mix temperatures were also tested.

The findings indicated that in all cases there was no significant difference in 28 day concrete compressive strengths when initial curing was extended from 24 hours to 48 hours. There was, however, a significant change in the 28 day compressive strength when the initial curing temperature was varied outside the specified 15°C - 25°C range. For initial curing temperatures below 15°C, the increase in compressive strength on concretes made with 100 Type 10 cement is approximately double that obtained on concretes made with 75% Type 10/25% GGBFS cement. Above 25°C, the decrease in compressive strength on concretes made with Type 10 cement is equal to that obtained on concrete made with 75% type 10/25% GGBFS cement. Furthermore, the decrease in strength at initial curing temperatures above 25°C is almost immediate. It was also noted that for concretes containing 75% type 10/25% GGBFS cement, cylinders initially cured at the minimum specified temperature of 15°C were too green when demoulded at the minimum specified time of 16 hours.

Based on the conclusions of this study it is recommended the present requirements of initial curing period be relaxed to 48 hours where conditions warrant it. Measures to ensure compliance with the present specified initial curing temperature range of 15°C - 25°C should be observed. Caution should be exercised to avoid premature demoulding of concrete cylinders cast form concrete containing GGBFS cement and initially cured near the minimum specified initial curing temperature of 15°C.

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We wish to thank the technicians in the Eastern Regional Laboratory in Kingston who did the laboratory testing. We also wish to thank the field technicians across the province who did the testing in the field.

THE EFFECT OF VARYING FIELD CURING CONDITIONS ON THE 28-DAY STRENGTH OF CONCRETE

INTRODUCTION

Hot or cold weather not only introduces problems in manufacturing, placing and curing concrete but also impacts on the initial curing and handling of concrete cylinders used in determining the 28 day compressive strength properties representative of the quality of the hardened concrete. [1, 2, 3, 4, 5]

CSA Standard A23.2-3C[6] specifies the initial curing conditions for concrete compressive strength cylinders. Concerns have been expressed by Regional Quality Assurance Sections regarding the specified time and temperature constraints, particularly on remote job site locations. Experimental work in the MTC Thunder Bay laboratory[7] has found no significant difference in strength where standard initial curing is extended from 24 hours to 48 hours. Furthermore ASSHTO has recently relaxed the time requirements to 48 hours where warranted. On the other hand in conjunction with the introduction of the performance specifications for concrete compressive strength, contractors are concerned that some departures from the standard procedures for the making, curing and testing of concrete cylinders may unjustly penalize them. As a result, an investigation was carried out in both the field and laboratory to evaluate the effects on 28 day compressive strength of varying the initial curing conditions.

OBJECTIVES

The objectives of this project were to determine:

1. the influence of varying the initial cylinder curing and demoulding time in the field from 24 hours to 48 hours and 72 hours on the 28 day compressive strength of concrete. Cylinders were to be made and tested using concrete with 100% Type 10 cement and concrete with 75% Type 10/25% ground granulated blast furnace slag (GGBFS) cement.

2. the influence of varying the initial cylinder curing and demoulding time in the laboratory on the 28 day compressive strength of concrete. Cylinders were to be made and tested using concrete with 100% Type 10 cement and concrete with 75% Type 10/25% GGBFS cement.

3. the effect of (2) above when the initial curing temperature is varied over the range 5°C to 35°C.

4. the effect of (2) and (3) above when the initial temperature of the concrete mix is varied from 10°C to 30°C.

FIELD TESTS

Each Region was requested to carry out the following field tests on at least one job site where 30 MPa and/or 35 MPa concrete was used: (Appendix A)

(i) one set of cylinders to be made, cured and tested strictly in accordance with the standard procedures,

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(ii) one set of cylinders as in (i) above but the initial (field) curing should be 40-48 hours,

(iii) one set of cylinders as in (i) above but the initial (field) curing should be 64-72 hours.

The above was requested for each class of concrete. All three sets of cylinders were cast from the same sample of concrete. A record of the minimum/maximum temperature during the initial curing condition was requested.

LABORATORY TESTS

Standard Materials

The standard materials used in all laboratory mixes were as follows.

(a) Air Entraining Admixture - a neutralized vinsol resin complying with the requirements of OPSS Form 1303[8], (Protex AES)

(b) Chemical Admixture - a strength increasing normal setting admixture meeting the requirements of OPSS Form 1303[8] for Type SN (Prokrete N). It was used at a dosage of 250 mL per 100 kg cement.

(c) Fine Aggregate - a natural sand with a 2.640 bulk relative density (dry), 1.06 percent absorption and a 2.72 fineness modulus, (Sweets Sand and Stone, Seeley's Bay)

(d) Coarse Aggregate - a crushed dolomitic limestone with a 19 mm nominal maximum size, a 2.690 bulk relative density (dry), and 0.50 percent absorption (Wood's Quarry, Kingston). It had the following gradation:

Sieve	% Passing
19 mm	100
13.2 mm	67
9.5 mm	34
4.75 mm	0

(e) Water - tap water (City of Kingston)

(f) Cements - (i) Type 10 Portland Cement complying with the requirements of OPSS Form 1301[9] (CCL Bath)

(ii) GGBFS complying with the requirements of OPSS Form 1301 (Standard Slag, Fruitland)

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Concrete Mixes and Fabrication of Specimens

Two series of 30 MPa class air entrained concretes were manufactured. The first series contained 100% Type 10 cement and the second series contained 75% Type 10/25% GGBFS cement. Upon completion of testing for 28d compression tests of all 30 MPa mixes, a selected number of 35 MPa class air entrained concrete mixes were prepared using Type 10 cement only. All 30 MPa and 35 MPa class of concretes in this program were made with a cement content of 355 kg/m3 and 415 kg/m3 [11] respectively.

The concrete was mixed in a pan type mixer. All mixes were proportioned to produce a slump of 80 $\pm$ 10 mm and an entrained air content of 6 $\pm$ 1.0% as measured by the pressure meter. All tests of the fresh and hardened concrete were in accordance with the appropriate test methods of CSA Standard CAN 3-A23.2-M77.

Eight mixes were prepared for each series of 30 MPa class concrete. The only variables were the initial concrete mix temperature, initial curing temperature and demoulding time. For each mix, 2 identical 44 L batches of concrete were prepared and six 150 X 300 mm cylinders were cast from each batch. Three mixes were prepared for the 35 MPa concrete. The first two mixes followed the same procedures as for the 30 MPa concretes described above. For the third mix, 48.4 L, seven cylinders were cast from each batch. The mix proportions together with the test results on the plastic concrete are shown in Tables A, B and C.

Curing and Testing of Specimens

Sets of cylinders (1 set = 2 cylinders) for each designated demoulding time were established by making two batches for each mix and selecting one cylinder from each batch. For all mixes one set of cylinders was referenced as control with an initial curing temperature of 23 $\pm$ 2°C and demoulding time of 20 hours. The control cylinders were placed directly into the laboratory moist curing room immediately after casting. All remaining sets of cylinders were placed in a large insulated wooden box specially fabricated to contain all cylinders (except control) from one mix. Initial curing temperature inside the box was controlled with a thermostatically regulated electric fan heater. The air temperature inside the box was monitored at all times. Low curing temperatures were achieved by placing the box and contents outside the laboratory and performing the tests when the surrounding outside air temperature was below the specified initial curing temperature throughout the 72 hour duration of the initial curing phase.

All sets of cylinders placed in the curing box were initially cured at the designated curing temperature and removed from the curing box at the specified demoulding time varying between 16 to 72 hours with the exception of the third 35 MPa mix. Following demoulding, all cylinders were placed in the laboratory moist curing room and moist cured at 23 $\pm$ 2°C until 28d. For the third 35 MPa mix, all sets of cylinders placed in the curing box were removed at the specified time following initial curing and placed directly in the moist curing room. They were removed from the moist curing room at 20 hours to be demoulded and then immediately returned to be moist cured at 23 $\pm$ 2°C until 28d.

...4/-

DISCUSSION OF TEST RESULTS

Field Tests

The results of the field trials are shown in Table D and illustrated in Figure 1. No results were reported from Eastern Region. There was a wide variation in the initial curing temperatures amongst the contracts that the cylinders were made on. The range of initial curing temperatures as specified in CSA A23.2-3C (15°C - 25°C) was seldom complied with. Furthermore there were four contracts on which the initial curing was extended beyond three days. Nevertheless, when comparing the 28d compressive strength of the cylinders with extended initial curing to the corresponding cylinders demoulded at one day, there was neglible difference. The largest differences (maximum 4.6 MPa) were observed to occur when initial curing temperatures were experienced around the freezing mark (0°C).

Laboratory Tests

The results of the laboratory tests are shown in Table E, F and G and illustrated in Figures 2A, 2B and 2C. The following observations are noted:

1. For the 30 MPa class concretes using 100% Type 10 cement, there was generally neglible difference in the 28d compressive strengths of the cylinders for the various demoulding times when comparing only those cylinders initially cured in the curing box. A slight decrease was noted for the cylinders demoulded at 48 and 72 hours when initial curing temperatures were in the specified range (15°C to 23°C).

2. For the 30 MPa class concretes using 75% Type 10/25% GGBFS cement, when comparing the 28d compressive strengths of the cylinders initially cured in the curing box, there was a noted decrease in the compressive strength for all initial curing temperatures when initial curing was extended to 72 hours. The decrease for cylinders initially cured 48 hours occurred only for initial curing temperatures 21°C or above.

3. For the 30 MPa class concretes using 100% Type 10 cement, the compressive strengths of cylinders cured at 5°C were 10 - 15% greater than that of the corresponding reference cylinders cured at 23°C whereas for cylinders cured at 35°C, the compressive strengths were 10 - 15% less than that of the corresponding reference cylinders cured at 23°C.

4. For the 30 MPa class concretes using 75% Type 10/25% GGBFS cement, the compressive strengths of cylinders cured at 5°C were about 5% greater than that of the corresponding reference cylinders cured at 23°C whereas for cylinders cured at 35°C, the compressive strengths were 10 - 15% less than that of the corresponding reference cylinders cured at 23°C.

5. For the 30 MPa class concretes, the average compressive strength of all reference cylinders for 100% Type 10 cement was 34.9 MPa and for 75% Type 10/25% GGBFS cement was 39.8 MPa.

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6. For both series of 30 MPa class concretes, there was a significant decrease in the compressive strength of the reference cylinders for all mixes batched at the highest concrete mix temperature of 30°C. After adjustments of 6% for each 1% difference in air content were applied to the compressive strengths of all reference mixes for 100% Type 10 cement the average 28d compressive strength of the reference mixes at 30°C was 33.2 MPa vs 35.2 MPa average for all remaining reference mixes; for 75% Type 10/25% GGBFS cement the average 28d compressive strength of the reference mixes at 30°C was 36.4 MPa vs 39.8 MPa average for all remaining reference mixes.

   There was neglible difference in the compressive strength of the reference mixes batched @ 10°C vs 20°C for either series.

7. For mixes having 75% Type 10/25% GGBFS cement, the cylinders (cured initially at 5°C or with low mix temperature 10°C and cured at 15°C) were noted to be too green and could not be properly demoulded when demoulded at 16 hours. This was reflected in the low strengths observed with such cylinders.

8. For the 35 MPa class concretes, the compressive strengths of the cylinders cured at 35°C were 5 - 10% (exception 72 hrs. mixed at 20°C) lower than that of the corresponding reference cylinders cured at 23°C.

9. For the 35 MPa class concretes, the 28d compressive strengths of the cylinders initially cured at 35°C for periods between 2 hours to 12 hours at 2 hour intervals, were 8 - 14% lower than that of the corresponding reference cylinders cured at 23°C.

CONCLUSIONS

The results of the tests from the field and laboratory investigation indicate that prolonged initial field curing of cylinders up to 48 hrs. has neglible effects on the 28d compressive strengths provided initial curing temperatures are maintained within the specified range of 15°C to 25°C.

The temperature of the surrounding environment during initial curing has a major influence on the 28d compressive strengths. Cylinders cured at temperatures below the specified range (15°C-25°C) show a marked increase in 28d compressive strengths. The increase on concretes made with 100% Type 10 cement is approximately double that obtained on concretes made with 75% Type 10/25% GGBFS cement. Temperatures above the specified range (15°C-25°C) show a marked decrease in 28d compressive strengths. Both concretes with 100% Type 10 cement and those with 75% Type 10/25% GGBFS cement are equally affected.

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The decrease in compressive strength of concrete cylinders exposed to high temperatures during initial curing is almost immediate. The laboratory tests indicated that the loss in compressive strength after exposure of cylinders to 35°C (hot weather) for 2 hours initially is the same as for up to 72 hours. Such high temperature effects could also be obtained during warm weather by exposing the cylinders immediately after casting to direct sunlight for prolonged periods.

RECOMMENDATIONS

The present requirements of initial curing period of 16-24 hours should be relaxed to 48 hours in accordance with current ASSHTO requirements.

It is essential that the present requirements on initial curing temperature (15°C-25°C) be strictly complied with. Where a suitable facility with a thermostatically controlled environment within the range of 15°C to 25°C is not readily available, specially equipped portable boxes (trailers) with adequate equipment to control temperatures within the specified temperature range should be required to be available for use on all contracts whenever/wherever concrete cylinders are cast. All cylinders should be placed in the boxes immediately following casting. Where such equipment is not in use, a record of the maximum and minimum temperatures during initial curing should be kept. Where temperatures are outside the specified limits, the cylinder test results should not be used for acceptance purposes.

Where temperatures during initial curing near the minimum specified 15°C are experienced, the minimum demoulding time for cylinders cast from concrete containing 75% Type 10/25% GGBFS cement should be extended from 16 hours to 20 hours.

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TABLE A

CONCRETE MIX PROPORTIONS AND TEST RESULTS ON FRESH CONCRETE

30 MPa CLASS CONCRETE; CEMENT - 100% TYPE 10

LAB MIX#	BATCH	BATCH QUANTITIES						TEST RESULTS-FRESH CONCRETE				
		FINE AGG. (kg)	COARSE AGG. (kg)	CEMENT (kg)	WATER (TOTAL) (kg)	WR (PROKRETE) (mL)	AEA (PRO AIR) (mL)	CONCRETE TEMP. °C	AIR CONTENT (%)	SLUMP (mm)	EFF. W/C RATIO	DENSITY (kg/m3)
1	A	30.4	49.4	15.6	7.18	39.0	4.0	12.0	5.5	90	0.423	2334
	B	30.4	49.4	15.6	7.18	39.0	4.0	12.5	5.0	85	0.423	2341
2	A	30.4	49.4	15.6	7.18	39.0	4.0	10.0	5.3	85	0.423	2341
	B	30.4	49.4	15.6	7.18	39.0	7.0	10.0	6.6	80	0.423	2334
3	A	30.4	49.4	15.6	7.38	39.0	7.0	20.0	6.0	70	0.436	-
	B	30.4	49.4	15.6	7.38	39.0	7.0	20.0	6.8	75	0.436	-
4	A	30.4	49.4	15.6	7.38	39.0	7.0	20.0	6.2	75	0.436	2327
	B	30.4	49.4	15.6	7.38	39.0	7.0	20.0	5.8	90	0.436	2327
5	A	30.4	49.4	15.6	7.18	39.0	7.0	22.0	6.6	85	0.423	2320
	B	30.4	49.4	15.6	7.18	39.0	7.0	22.0	5.5	70	0.423	2342
6	A	30.4	49.4	15.6	7.18	39.0	7.0	22.0	6.8	70	0.423	2313
	B	30.4	49.4	15.6	7.18	39.0	7.0	22.0	6.4	75	0.423	2306
7	A	30.4	49.4	15.6	7.28	39.0	7.0	28.0	5.3	65	0.430	2334
	B	30.4	49.4	15.6	7.28	39.0	7.0	29.0	5.0	65	0.430	2341
8	A	30.4	49.4	15.6	7.78	39.0	7.0	30.0	5.5	85	0.462	-
	B	30.4	49.4	15.6	7.78	39.0	7.0	31.0	5.9	85	0.462	-

TABLE B

CONCRETE MIX PROPORTIONS AND TEST RESULTS ON FRESH CONCRETE

30 MPa CLASS CONCRETE; CEMENT - 75% TYPE 10 / 25% GGBFS

LAB MIX#	BATCH	BATCH QUANTITIES						TEST RESULTS-FRESH CONCRETE				
		FINE AGG. (kg)	COARSE AGG. (kg)	CEMENT (kg)	WATER (TOTAL) (kg)	WR (PROKRETE) (mL)	AEA (PRO AIR) (mL)	CONCRETE TEMP. °C	AIR CONTENT (%)	SLUMP (mm)	EFF. W/C RATIO	DENSITY (kg/m3)
1	A	30.4	49.4	15.6	7.38	39.0	7.0	9.0	6.4	85	0.435	-
	B	30.4	49.4	15.6	7.38	39.0	7.0	9.0	6.2	85	0.435	-
2	A	30.4	49.4	15.6	7.68	39.0	7.0	13.0	5.8	80	0.455	2334
	B	30.4	49.4	15.6	7.68	39.0	7.0	13.0	6.5	85	0.455	2327
3	A	30.4	49.4	15.6	7.38	39.0	7.0	18.0	5.4	85	0.436	-
	B	30.4	49.4	15.6	7.38	39.0	7.0	18.0	6.6	85	0.436	2327
4	A	30.4	49.4	15.6	7.38	39.0	7.0	21.0	5.6	80	0.436	2334
	B	30.4	49.4	15.6	7.38	39.0	7.0	21.0	5.0	80	0.436	2341
5	A	30.4	49.4	15.6	7.68	39.0	7.0	21.0	5.0	85	0.455	2348
	B	30.4	49.4	15.6	7.68	39.0	7.0	21.0	5.3	85	0.455	2341
6	A	30.4	49.4	15.6	7.38	39.0	7.0	22.0	6.0	80	0.436	2320
	B	30.4	49.4	15.6	7.68	39.0	7.0	22.0	6.0	75	0.436	2334
7	A	30.4	49.4	15.6	7.66	39.0	7.0	28.0	5.0	85	0.454	2334
	B	30.4	49.4	15.6	7.66	39.0	7.0	28.0	4.9	90	0.454	2327
8	A	30.4	49.4	15.6	7.60	39.0	7.0	28.0	5.3	85	0.450	2327
	B	30.4	49.4	15.6	7.60	39.0	7.0	29.0	5.4	85	0.450	2327

TABLE C
CONCRETE MIX PROPORTIONS AND TEST RESULTS ON FRESH CONCRETE
35 MPa CLASS CONCRETE; CEMENT - 100% TYPE 10

LAB MIX#	BATCH	BATCH QUANTITIES						TEST RESULTS-FRESH CONCRETE				
		FINE AGG. (kg)	COARSE AGG. (kg)	CEMENT (kg)	WATER (TOTAL) (kg)	WR (PROKRETE) (mL)	AEA (PRO AIR) (mL)	CONCRETE TEMP. °C	AIR CONTENT (%)	SLUMP (mm)	EFF. W/C RATIO	DENSITY (kg/m3)
1	A	28.2	49.4	18.3	7.39	46.0	8.5	20.0	6.0	80	0.373	2320
	B	28.2	49.4	18.3	7.39	46.0	8.5	20.0	6.8	80	0.373	2306
2	A	28.2	49.4	18.3	7.40	46.0	8.0	30.0	5.7	70	0.373	2313
	B	28.2	49.4	18.3	7.40	46.0	8.0	29.0	5.0	80	0.373	2334
3	A	31.0	54.3	20.1	8.40	50.0	9.0	19.0	5.3	75	0.388	2341
	B	31.0	54.3	20.1	8.40	50.0	9.3	20.0	6.4	80	0.388	2327

TABLE 3

REGION	CLASS OF CONCRETE (MPa)	CEMENT		INITIAL CURING TEMP. RANGE (°C)	DEMOULDING TIME (HOURS)	COMPRESSIVE STRENGTH AT 28 DAYS (MPa)		
		100% TYPE 10	75% TYPE 10/ 25% GGBFS			CYLINDER#1	CYLINDER#2	AVERAGE
CENTRAL	35		X	0-15	24	50.0	51.4	50.7
				0-16	47	52.4	52.2	52.3
				0-16	96	54.1	53.2	53.7
CENTRAL	35		X	10-20	21	45.1	45.6	45.4
				8-21	117	46.7	44.1	45.4
CENTRAL	30		X	10-15	24	32.7	33.2	32.8
				2-15	120	34.1	35.4	34.8
CENTRAL	35	X		22-25	20	39.1	39.6	39.4
				16-33	44	39.3	38.2	38.8
				13-34	68	38.6	39.8	39.2
CENTRAL	30		X	20-24	17	37.3	37.1	37.2
				22-32	41	36.1	35.4	35.8
				12-32	65	35.0	35.9	35.5
CENTRAL	30	X		20-24	25	38.5	36.0	37.3
				20-24	47	38.1	37.9	38.0
				19-24	71	37.2	37.7	37.5
NORTHWEST	30		X	5-19	21	41.4	42.2	41.8
				5-19	47	41.9	40.9	41.4
				5-19	71	40.5	41.4	41.0
SOUTHWEST	30		X	10-18	25	35.7	36.8	36.3
				10-18	48	38.0	38.3	38.2
SOUTHWEST	30		X	7-22	24	38.7	39.7	39.2
				7-22	89	39.0	37.6	38.3
NORTHERN	30	X		10	18	36.7	36.8	36.8
				10	42	37.8	37.3	37.6
				10	64	37.3	36.8	37.1
NORTHERN	20	X (TREMIE)		-	24	35.1	34.9	35.0
				-	46	33.6	33.9	33.8
				-	70	33.6	33.9	33.8
NORTHERN	30	X		10-15	24	41.7	40.3	41.0
				-2-15	46	38.7	39.2	39.0
				-2-16	69	38.5	38.7	38.6
NORTHERN	35	X		-1-10	24	51.2	47.6	49.4
				-1-16	48	45.6	46.1	45.9
				-1-16	72	42.4	47.1	44.8

TABLE E

30 MPa CONCRETE; CEMENT - 100% TYPE 10

CONCRETE MIX NO.	INITIAL CONCRETE TEMPERATURE (°C)		INITIAL CURING TEMP. RANGE (°C)	DEMOULDING TIME (HOURS)	COMPRESSIVE STRENGTH AT 28 DAYS (MPa)			DIFFERENCE FROM REF. MIX
	BATCH A	BATCH B			BATCH A	BATCH B	AVERAGE	
1	12	12.5	2-5	16	39.5	37.8	38.7	3.1
			2-5	20	40.3	41.0	40.7	5.1
			2-5	24	43.0	40.5	41.8	6.2
			2-5	48	43.6	38.7	41.2	5.6
			2-9	72	41.9	39.5	40.7	5.1
			22	20	36.6	34.6	35.6	REF.
2	10	10	15-16	16	40.3	37.9	39.1	2.5
			15-16	20	36.7	35.9	36.3	-0.3
			15-16	24	38.1	38.4	38.3	1.7
			15-16	48	37.8	35.9	36.9	0.3
			15-16	72	35.9	38.1	37.0	0.4
			23	20	37.3	35.9	36.6	REF.
3	20	20	3-5	16	40.0	37.6	38.8	3.8
			3-6	20	39.6	37.2	38.4	3.4
			3-6	24	39.8	38.1	39.0	4.0
			3-6	48	40.9	38.1	39.5	4.5
			3-7	72	39.0	37.6	38.3	3.3
			21	20	36.0	33.9	35.0	REF.
4	20	20	14-15	16	39.6	36.1	37.9	3.6
			14-15	20	37.7	37.2	37.5	3.2
			14-18	24	38.1	35.9	37.0	2.7
			14-18	48	34.7	35.5	35.1	0.8
			14-18	72	35.6	36.5	36.1	1.8
			22	20	33.2	35.4	34.3	REF.

TABLE E (cont'd)
30 MPa CONCRETE; CEMENT - 100% TYPE 10

CONCRETE MIX NO.	INITIAL CONCRETE TEMPERATURE (°C)		INITIAL CURING TEMP. RANGE (°C)	DEMOULDING TIME (HOURS)	COMPRESSIVE STRENGTH AT 28 DAYS (MPa)			DIFFERENCE FROM REF. MIX
	BATCH A	BATCH B			BATCH A	BATCH B	AVERAGE	
5	22	22	23	16	34.6	36.8	35.7	1.2
			23	20	33.9	35.1	34.5	0.0
			22-23	24	35.1	35.9	35.5	1.0
			22-23	48	35.4	32.4	33.9	-0.6
			22-23	72	32.4	31.7	32.1	-2.4
			23	20	34.4	34.6	34.5	REF.
6	22	22	35	16	27.4	29.8	28.6	-6.1
			35	20	27.6	30.3	29.0	-5.7
			35	24	30.0	29.5	29.8	-4.9
			35	48	28.0	28.0	28.0	-6.7
			35	72	28.5	27.3	27.9	-6.8
			22	20	34.7	34.6	34.7	REF.
7	28	29	23-24	16	33.4	35.4	34.4	-1.4
			22-24	20	34.0	35.1	34.6	-1.2
			22-24	24	34.1	34.7	34.4	-1.4
			22-24	48	32.8	34.0	33.4	-2.4
			22-24	72	33.2	34.3	33.8	-2.0
			22	20	35.6	36.0	35.8	REF.
8	30	31	35	16	31.4	28.9	30.2	-2.7
			34-35	20	31.2	30.1	30.7	-2.2
			34-35	24	31.2	28.3	29.8	-3.1
			34-35	48	30.8	26.1	28.5	-4.4
			34-36	72	30.3	28.9	29.6	-3.3
			23	20	33.4	32.4	32.9	REF.

TABLE F

30 MPa CONCRETE; CEMENT - 75% TYPE 10/25% SLAG

CONCRETE MIX NO.	INITIAL CONCRETE TEMPERATURE (°C)		INITIAL CURING TEMP. RANGE (°C)	DEMOULDING TIME (HOURS)	COMPRESSIVE STRENGTH AT 28 DAYS (MPa)			DIFFERENCE FROM REF. MIX
	BATCH A	BATCH B			BATCH A	BATCH B	AVERAGE	
1	9	9	2-5	16*	43.3	42.8	38.7	2.6
			2-5	20	41.9	43.0	40.7	2.0
			2-8	24	43.0	41.2	41.8	1.6
			2-8	48	43.0	42.3	41.2	2.2
			2-8	72	41.9	40.0	40.7	0.5
			21	20	38.7	42.2	35.6	REF.
2	13	13	14-15	16*	41.2	42.0	39.1	0.4
			14-15	20	41.2	41.9	36.3	0.4
			14-16	24	42.2	41.4	38.3	0.6
			14-16	48	42.2	40.6	36.9	0.2
			14-16	72	40.5	40.7	37.0	-0.6
			23	20	41.9	40.5	36.6	REF.
3	18	18	5	16*	35.4	38.5	38.8	-1.8
			5	20	42.7	38.2	38.4	1.7
			5-7	24	41.9	39.6	39.0	2.0
			5-7	48	41.6	41.4	39.5	2.7
			4-7	72	35.4	40.3	38.3	-0.9
			21	20	38.7	38.9	35.0	REF.
4	21	21	14-15	16	42.1	41.1	37.9	0.4
			14-15	20	42.7	37.1	37.5	-1.5
			14-15	24	40.9	37.6	37.0	-2.1
			14-18	48	41.2	41.4	35.1	-0.1
			14-15	72	40.7	40.7	36.1	-0.7
			22	20	41.4	34.4**	34.3	REF.

NOTES :

* CYLINDERS TOO GREEN @ 16 HRS; DEMOULDED @ 20 HRS.

** BAD BREAK (NOT INCLUDED IN AVERAGE).

TABLE F (cont'd)
30 MPa CONCRETE; CEMENT - 75% TYPE 10/ 25% SLAG

CONCRETE MIX NO.	INITIAL CONCRETE TEMPERATURE (°C)		INITIAL CURING TEMP. RANGE (°C)	DEMOULDING TIME (HOURS)	COMPRESSIVE STRENGTH AT 28 DAYS (MPa)			DIFFERENCE FROM REF. MIX
	BATCH A	BATCH B			BATCH A	BATCH B	AVERAGE	
5	21	21	22-23	16	39.5	40.9	40.2	1.2
			22-23	20	40.1	40.7	40.4	1.4
			22-23	24	40.5	40.1	40.3	1.3
			22-23	48	40.0	35.1	37.6	-1.4
			22-23	72	36.6	35.5	36.1	-2.9
			24	20	37.0	41.0	39.0	REF.
6	22	22	35	16	35.7	36.0	35.9	-5.2
			35	20	35.9	34.6	35.3	-5.8
			35	24	33.2	36.0	34.6	-6.5
			33-35	48	34.7	33.5	34.1	-7.0
			33-35	72	34.9	35.0	35.0	-6.1
			23	20	40.7	41.4	41.1	REF.
7	28	28	23-25	16	38.7	39.5	39.1	0.3
			23-25	20	37.8	38.7	38.3	-0.5
			23-25	24	37.2	38.7	37.9	-0.9
			23-25	48	37.2	36.5	36.9	-1.9
			23-25	72	35.1	35.4	35.3	-3.5
			23	20	38.7	38.9	38.8	REF.
8	28	28	34-35	16	35.7	35.2	35.5	-2.4
			34-35	20	35.2	36.1	35.7	-2.2
			34-35	24	35.4	34.9	35.2	-2.7
			34-35	48	32.8	32.7	32.8	-5.1
			34-35	72	32.6	31.9	32.3	-5.6
			23	20	38.3	37.4	37.9	REF.

TABLE G

35 MPa CONCRETE; CEMENT - 100% TYPE 10

CONCRETE MIX NO.	INITIAL CONCRETE TEMPERATURE (°C)		INITIAL CURING		DEMOULDING TIME (HOURS)	COMPRESSIVE STRENGTH AT 28 DAYS (MPa)			DIFFERENCE FROM REF. MIX
	BATCH A	BATCH B	TEMP. (°C)	DURATION (HOURS)		BATCH A	BATCH B	AVERAGE	
1	20	20	35	16	16	33.6	33.0	33.3	-3.8
			35	20	20	33.9	32.1	33.0	-4.1
			35	24	24	33.9	33.0	33.5	-3.6
			35	48	48	32.7	32.6	32.7	-4.4
			35	72	72	37.4	40.5	39.0	1.9
			22	-	20	37.2	37.0	37.1	REF.
2	30	29	35	16	16	37.7	37.6	37.7	-2.1
			35	20	20	36.8	36.8	36.8	-3.0
			35	24	24	36.8	36.1	36.5	-3.3
			35	48	48	36.8	37.3	37.1	-2.7
			35	72	72	36.8	35.2	36.0	-3.8
			22	-	20	38.5	41.0	39.8	REF.
3	19	20	35	2	20	33.9	32.4	33.2	-5.4
			35	4	20	37.3	33.9	35.6	-3.0
			35	6	20	36.6	33.4	35.0	-3.6
			35	8	20	35.1	33.9	34.5	-4.1
			35	10	20	35.9	32.7	34.3	-4.3
			35	12	20	35.4	31.2	33.3	-5.3
			20	-	20	41.2	35.9	38.6	REF.

FIGURE #1

FIELD TRIALS

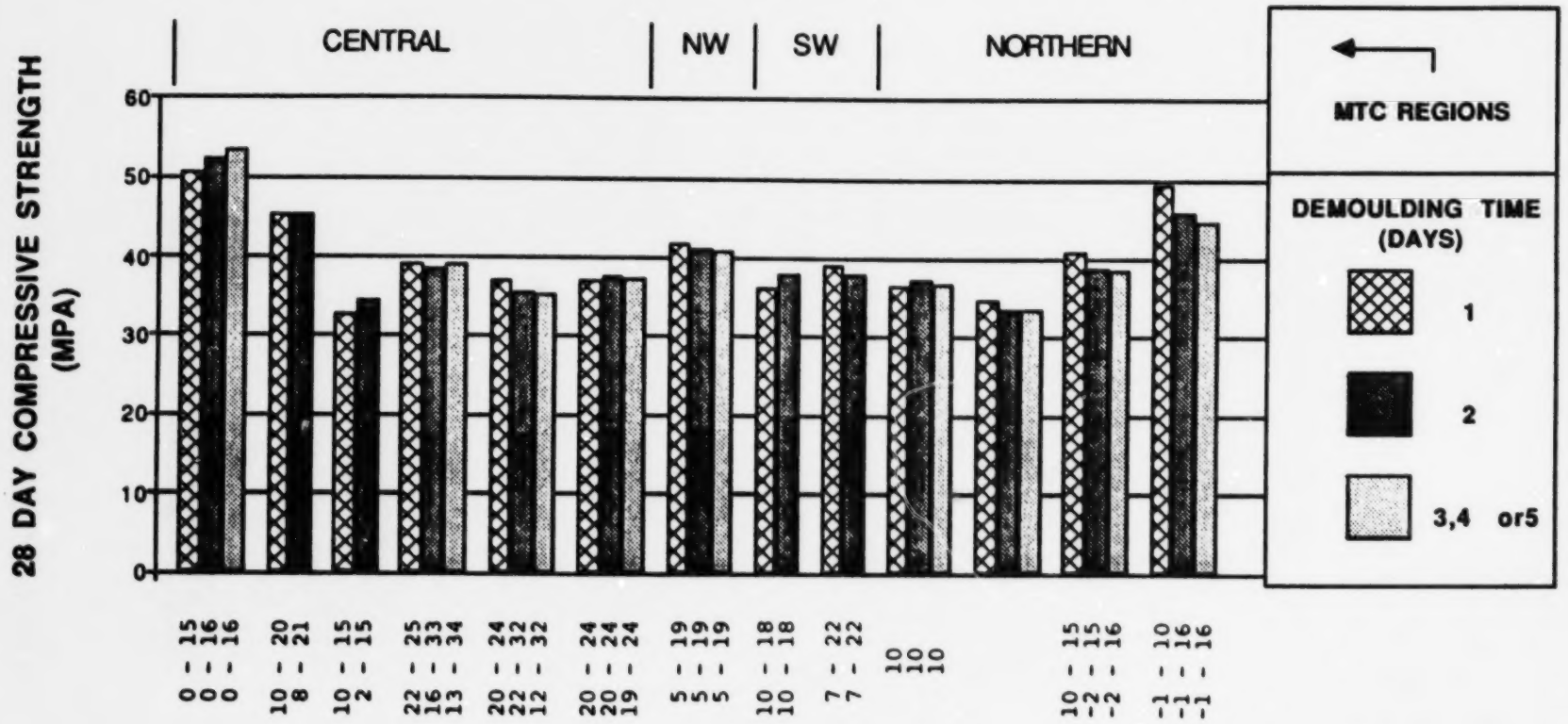
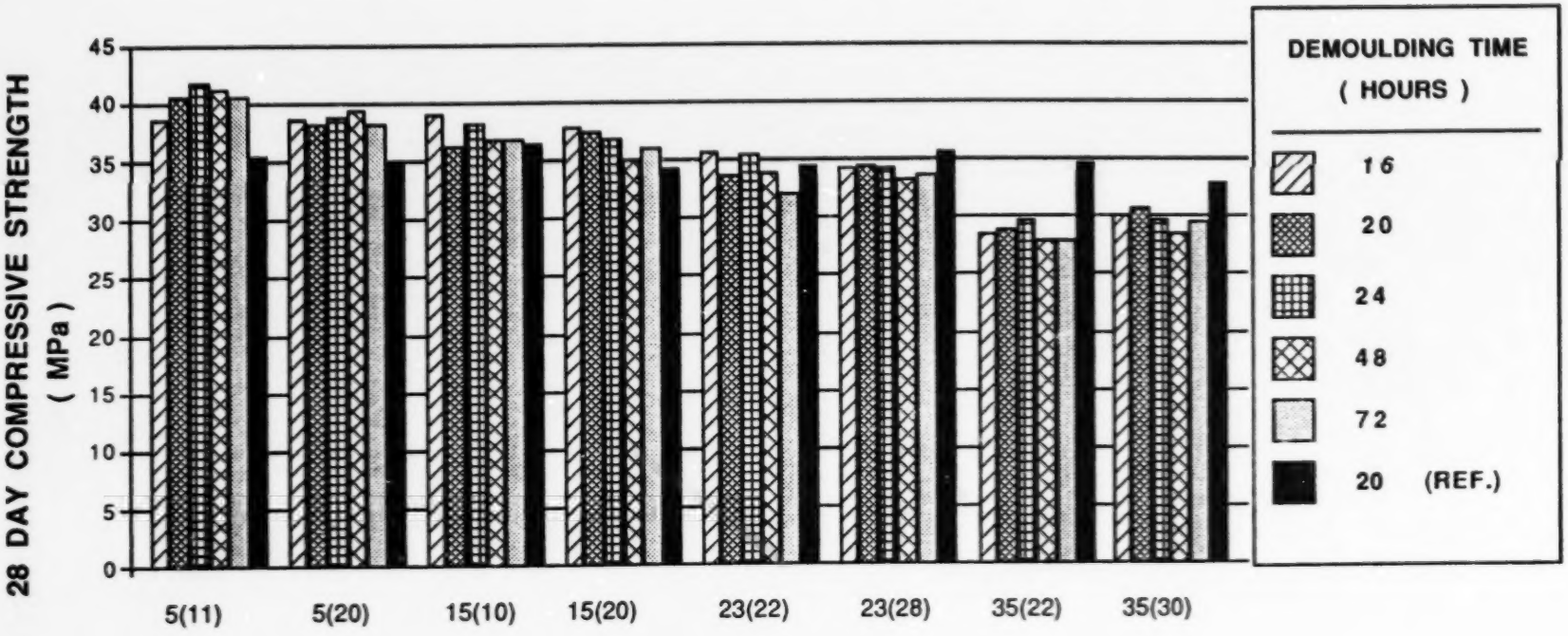


FIGURE # 2A

30 MPa CONCRETE; CEMENT - 100% TYPE 10

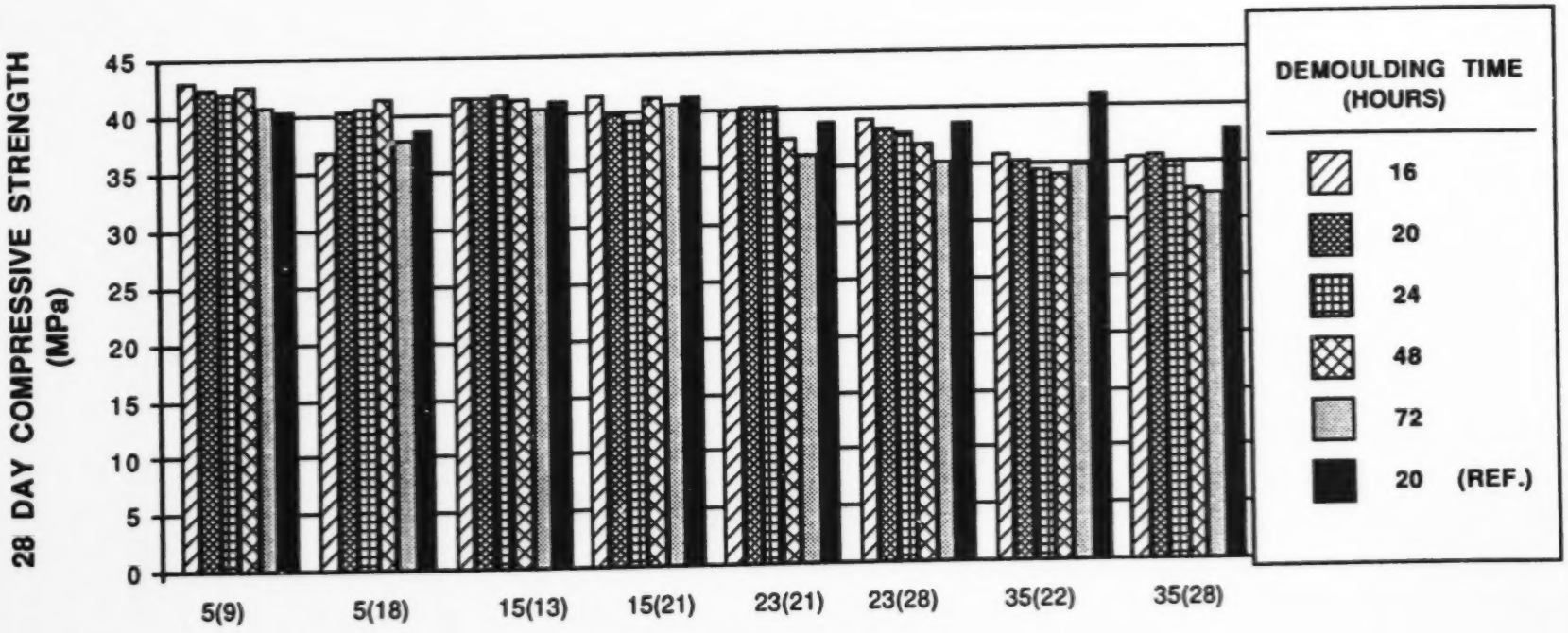


INITIAL CURING TEMPERATURE (°C)* (MIX TEMPERATURE (°C))

*NOT APPLICABLE TO REFERENCE MIXES

FIGURE # 2B

30 MPa CONCRETE; CEMENT - 75% TYPE 10/25% SLAG

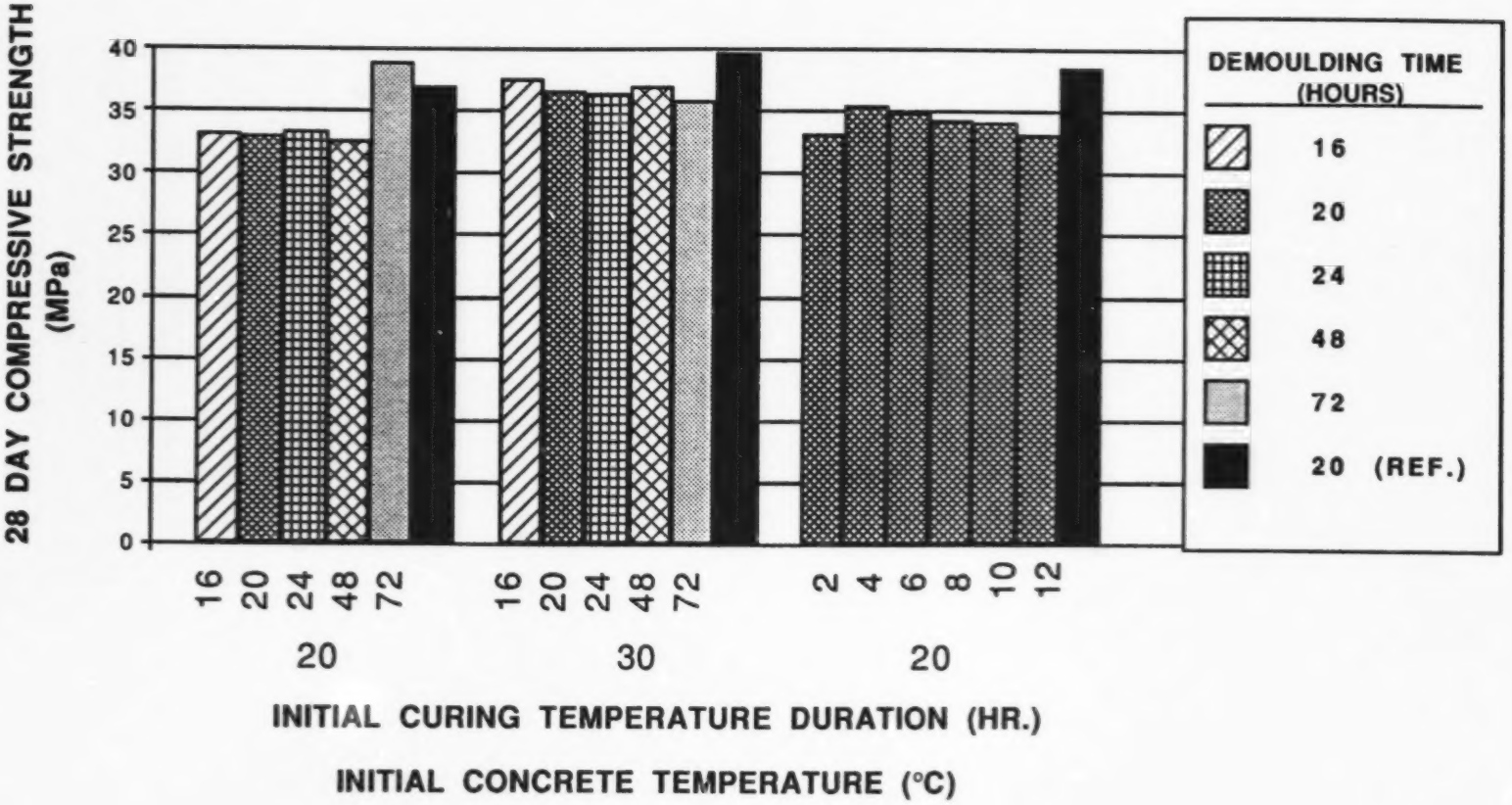


INITIAL CURING TEMPERATURE (°C)* (MIX TEMPERATURE (°C))

* NOT APPLICABLE TO REFERENCE MIXES

FIGURE # 2C

35MPa CONCRETE; CEMENT - 100% TYPE 10



NOTE: ALL CYLINDERS EXCEPT REFERENCE WERE INITIALLY CURED AT 35°C

APPENDIX A

To: Heads, Regional Quality Assurance Sections

Date: 84 08 22

From: Concrete Section
Engineering Materials Office
Room 111, Central Building
Downsview

Re: Initial (Field) Curing of Concrete Cylinders
Effect of Departures from Standard Procedures

In conjunction with an introduction of the performance type specifications in the future, contractors are concerned that some departures from the standard procedures for the making, curing and testing of contract concrete cylinders may unjustly penalize them. This concern necessitates some laboratory and field investigation to determine the effects of:

i) concrete temperature
ii) initial curing temperature
iii) demoulding time

and combinations of the three variables, on the 28d compressive strength.

A fair amount of valuable data on some of these effects has been obtained by Northwestern Region by laboratory and field testing. The laboratory part of this project at the Downsview laboratory will concentrate on the effects of combinations of the three variables. Concrete of 30 MPa and 35 MPa, each with Type 10 cement and Type 10 cement plus slag cement will be used in the tests.

In addition to the laboratory tests by the Downsview laboratory, we would like each Region to carry out the following field tests at at least one job site where 30 MPa and/or 35 MPa concrete is used:

i) one set of cylinders to be made, cured and tested strictly in accordance with the standard procedures

ii) one set of cylinders as in (i) above but the initial (field) curing should be 40-48h

iii) one set of cylinders as in (i) above but the initial (field) curing should be 64-72h

The above should be for each class of concrete. All three cylinder sets must be cast from the same concrete sample.

I would appreciate it if you could arrange for the tests and report the test results on the enclosed form separately for each cylinder set. Any questions regarding this program should be directed to Bob Newell or the undersigned.

B. Chojnacki

B. Chojnacki
Senior Concrete Engineer

BC/mc
Encl.

cc: R. Newell

Region _____

Contract No. _____

Mix Design No. _____

Date Cylinders Made _____ Time _____ ☐ a.m. ☐ p.m.

Concrete Temperature _____ ^{o}C

Initial (Field) Curing Conditions (where cylinders stored, temperature, max. - min.)

_____

_____

_____

_____

Date Cylinders Taken to Lab. _____ Time _____ ☐ a.m. ☐ p.m.

Date Cylinders Arrived in Lab. _____ Time _____ ☐ a.m. ☐ p.m.

Date Cylinders Demoulded _____ Time _____ ☐ a.m. ☐ p.m.

Laboratory Name and Location

_____

_____

_____

_____

Date Tested _____

Strength, MPa _____ _____ Avg. _____

Mass, kg _____ _____ _____

Report Prepared By

_____